

Search for Local Parity Violation in High-Energy Nuclear Collisions

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Outline

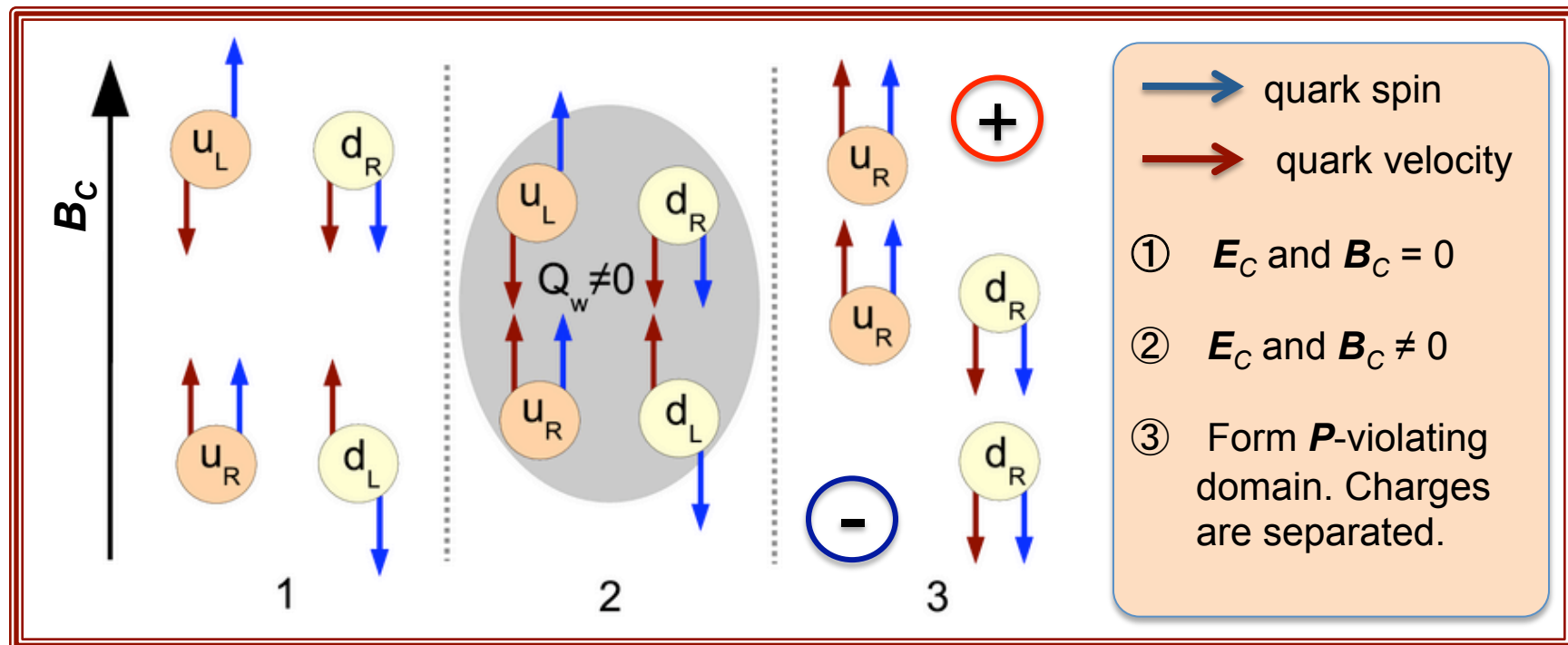
(1) What at the Questions

(2) Recent Results from STAR

(3) Next Step

QCD and Chiral Magnetic Effects

Strong interactions conserve parity. However, due to the topological structure in QCD, it is not forbidden to have parity (\mathbf{P}) violating effect locally in a hot and dense state, where Chiral symmetry is restored. Each of the \mathbf{P} -violating effect is restricted within a domain and domains are distributed randomly along a direction determined by its chromoelectric (\mathbf{E}_C) and chromomagnetic (\mathbf{B}_C) fields.



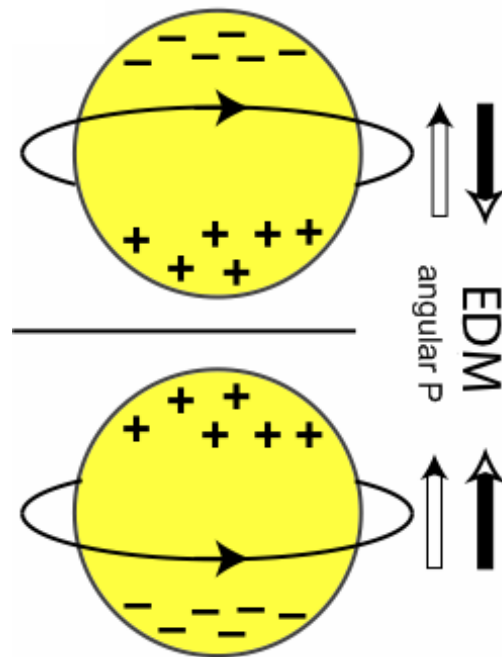
The Question

In the non-perturbative sector, study the structure of QCD vacuum:

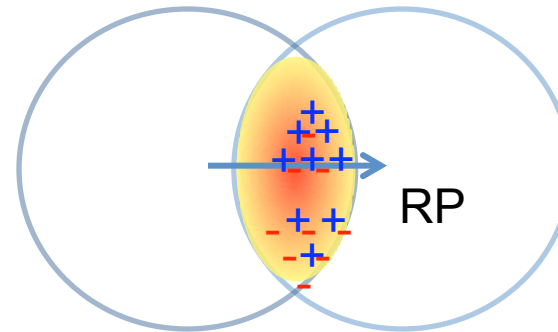
- (1) Chiral symmetry restoration
- (2) Deconfinement
- (3) Formation of QGP in high-energy nuclear collisions
- (4) ...

Local Parity Violation in QCD

(a) **Weak interaction***
parity violation

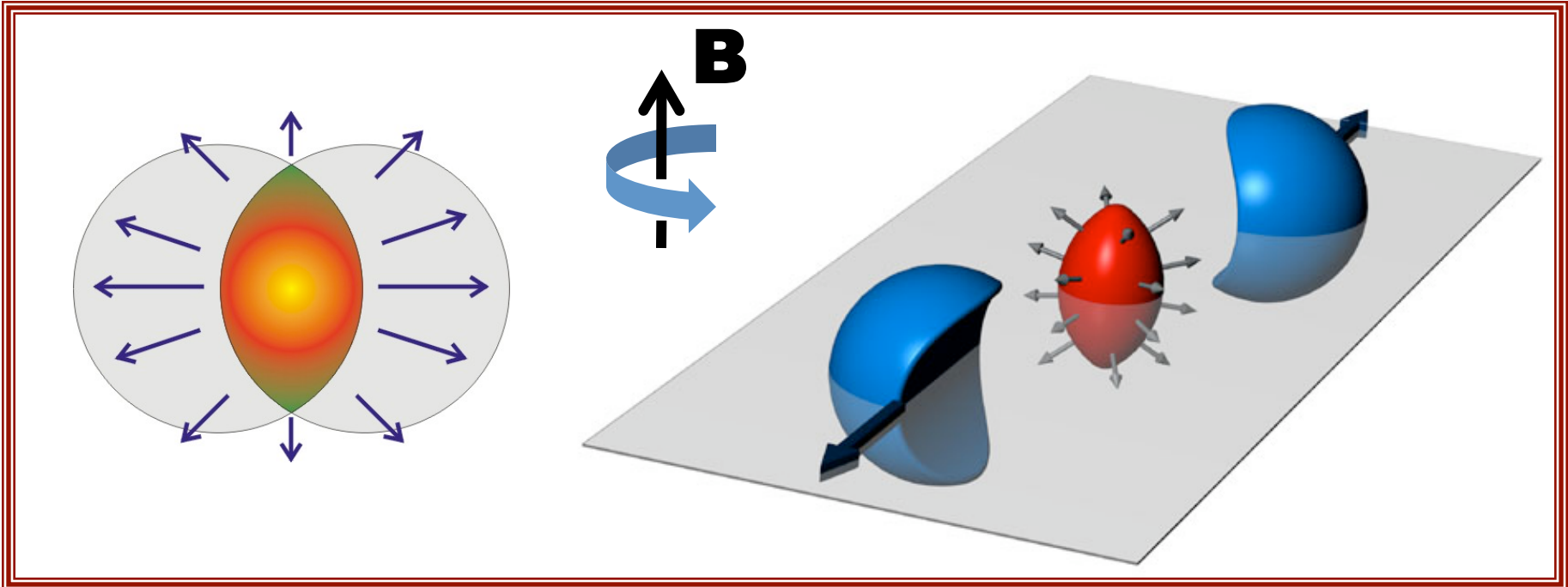


(b) **Strong interaction**
parity violation



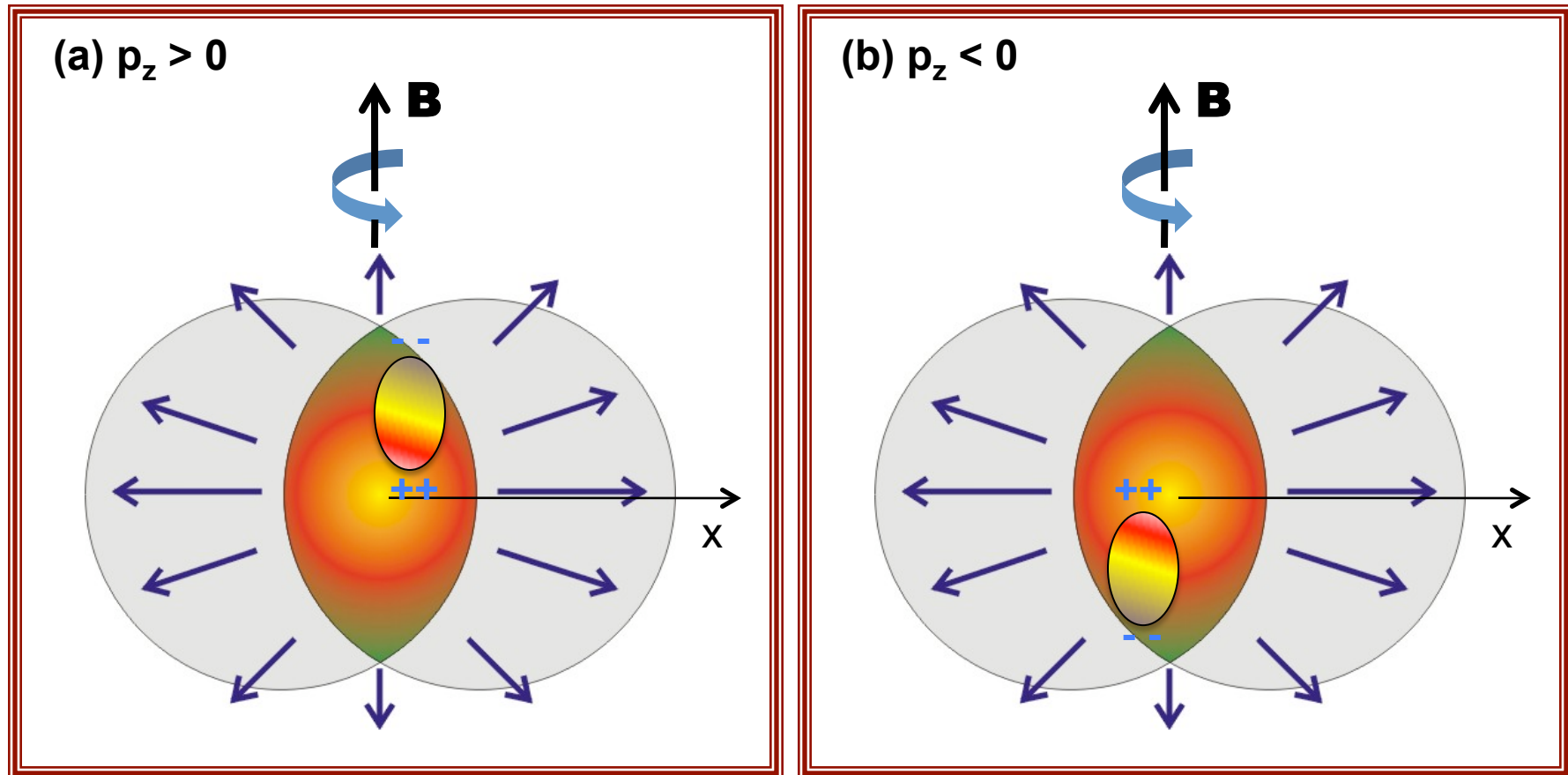
- Theory predicts, if parity is violated in strong interaction, one should observe charge separation w.r.t RP.

In Non-Central Heavy Ion Collisions



- (1) The QCD \mathbf{E}_C and \mathbf{B}_C should have the same symmetries as \mathbf{E} and \mathbf{B}
- (2) In non-central high-energy nuclear collisions, the **global angular momentum** direction could serve as the direction of the chromomagnetic field. The local \mathbf{P} -violating process may be observed through correlation measurements w.r.t. the reaction plane.

In Non-Central Heavy Ion Collisions



In case of P -violating, due to symmetry, we can test it at opposite rapidity windows:

- $x > 0$ and $p_z > 0$
- $x < 0$ and $p_z < 0$

I. Experimental study of spontaneous strong parity violation in heavy ion collisions at RHIC

S. Voloshin *et al.*

<http://orion.star.bnl.gov/protected/bulkcorr/voloshin/parity/paper/v26/paper.pdf>

Dividing out RP resolution

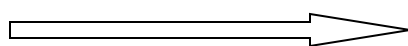
$$\langle \cos(\phi_a + \phi_\beta - 2\phi_c) \rangle = \langle \cos(\phi_a + \phi_\beta - 2\Psi_{RP}) \rangle v_{2,c}$$

$$|\eta| < 1.0 \quad (\text{Main TPC})$$

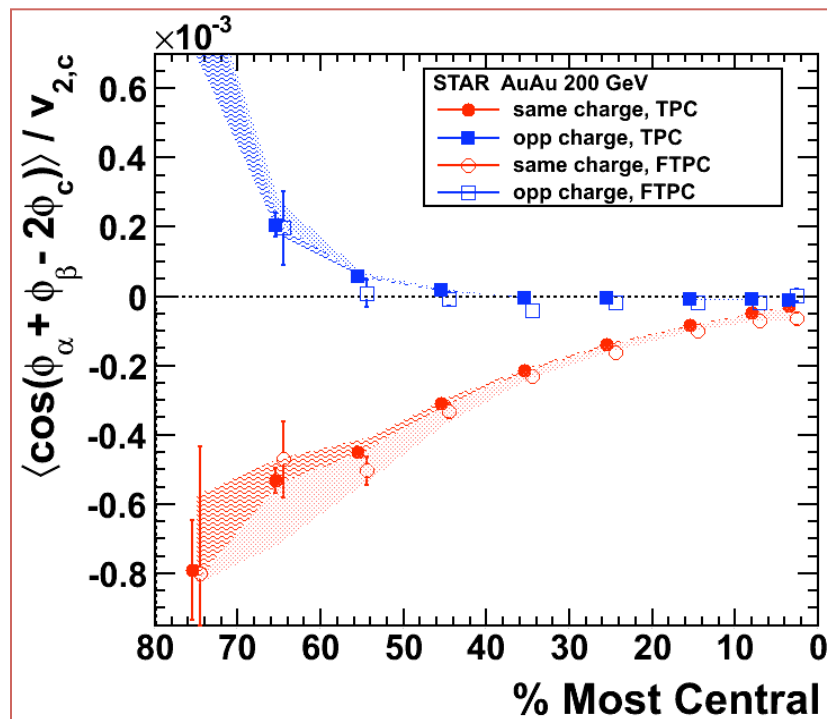
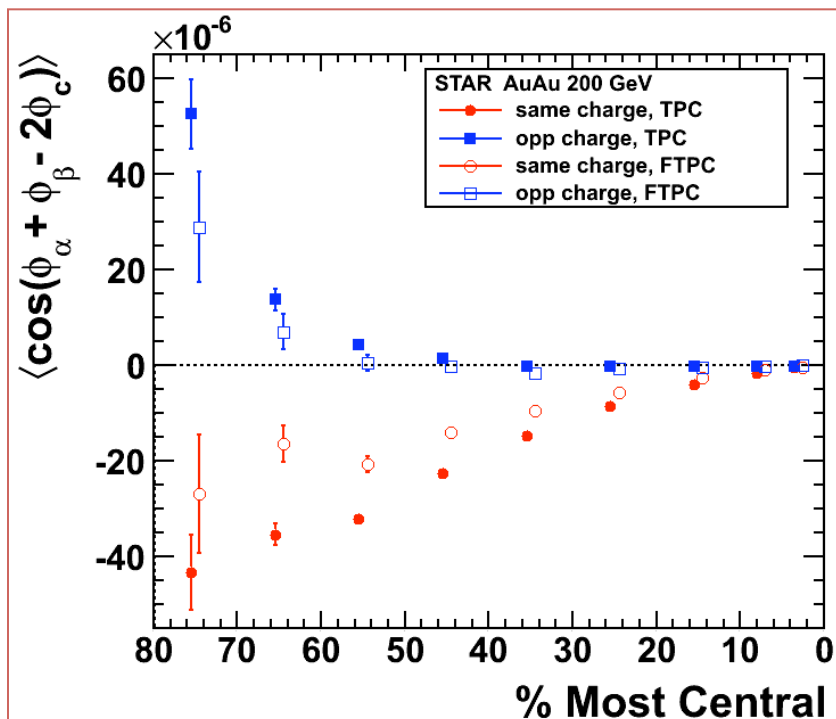
$$2.9 < |\eta| < 3.9 \quad (\text{FTPC})$$

Assuming: particle c not correlated with α and β , only with the R.P.!

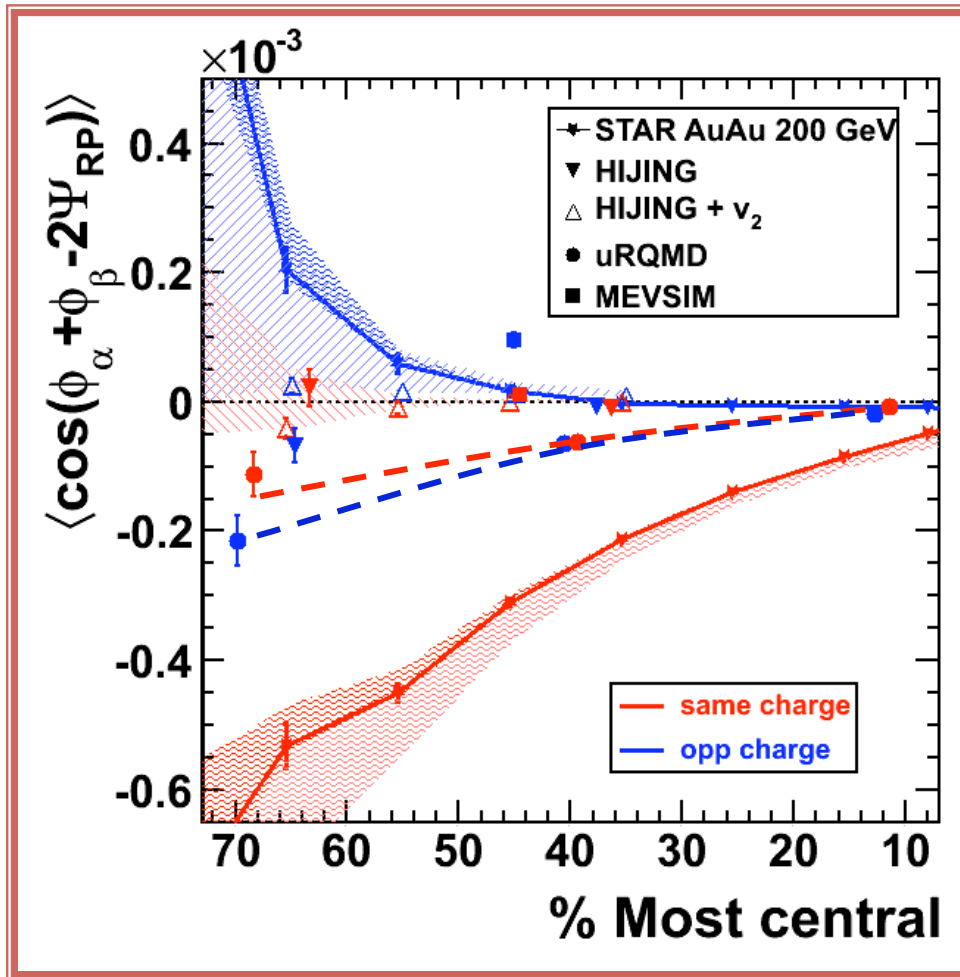
$$\langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle$$



$$\langle \cos(\phi_a + \phi_\beta - 2\Psi_{RP}) \rangle.$$



Data vs. Model Predictions



- Large difference in **like-sign** vs. **unlike-sign** correlations in the data compared to models that has no PV implemented.
- Bigger amplitude in **like-sign** correlations compared to **unlike-sign**.
- **Like-sign** and **unlike-sign** correlations are consistent with theoretical expectations



Pros and Cons

(1) Pros:

(2) Cons:

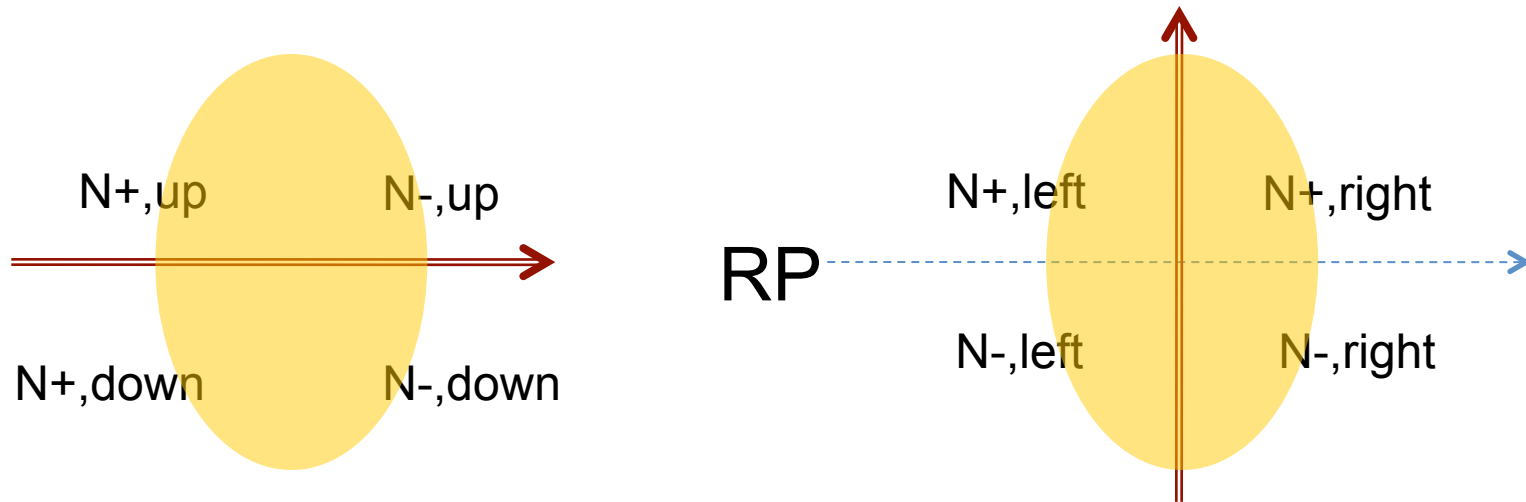
- *P*-even observable
- vulnerable for many sources of physical background

II. Charge Asymmetry w.r.t. Reaction Plane

Quan Wang and Fuqiang Wang

http://www.physics.purdue.edu/~wang187/doc/pv/bulk_20090513_Asym.pdf
http://www.physics.purdue.edu/~fqwang/protected/bulkcorr_20090506_cluster.pdf

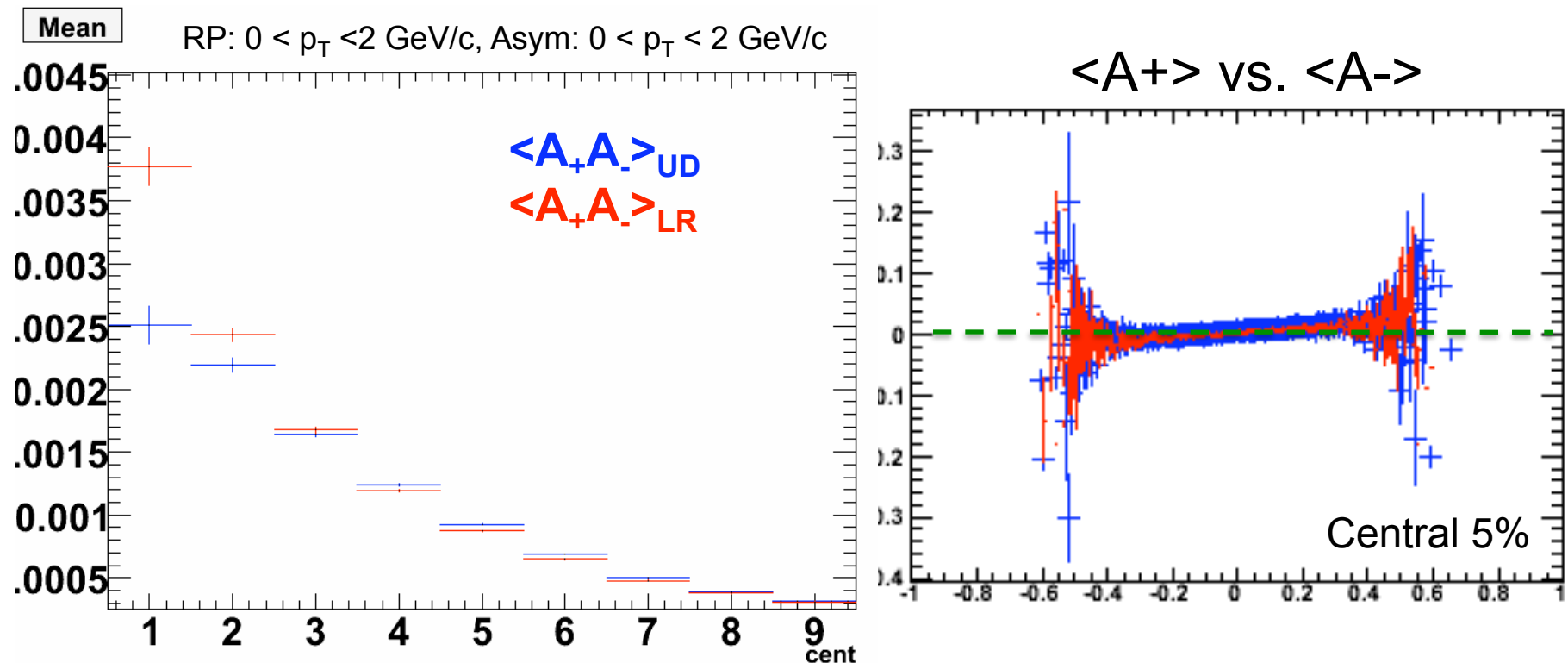
II. Direct PV Observable



$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}}$$

$$A_{\pm,LR} = \frac{N_{\pm,left} - N_{\pm,right}}{N_{\pm,left} + N_{\pm,right}}$$

Charge Asymmetry : Results



- If + and - are uncorrelated, $\langle A_+ A_- \rangle = \langle A_+ \rangle \langle A_- \rangle \sim 10^{-7}$ from $\langle A_{+/-} \rangle$ offsets.
- *P*-violating expectation: $\langle A_+ A_- \rangle < 0$.
- Data: $\langle A_+ A_- \rangle \sim 10^{-3}$, + and - are positively correlated \sim a few% asymmetry

→ **Asymmetry data inconsistent with PV**



Pros and Cons

(1) Pros:

- Direct PV observable

(2) Cons:

- Sensitivity yet to be studied



Nest Step:

- (1) Sergei: **Evidence for local strong parity violation in heavy ion collisions at RHIC**
- (2) Fuqiang: **Asymmetry data inconsistent with PV**